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The effect of environmental factors on the development of pine root systems

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Highlights: The effects of soil strength and temperature were investigated on young seedlings of two pine species. The rate of axial development of root systems of both species decreased with the increase in soil compaction, while both species had the largest increase in axial length at 15°C, which might be close to the optimal temperature for root elongation rate. These differences in the form and behaviour of the root systems of the two pines might be important for competition and integration of the species into the environmental management strategies.

Keywords: *Pinus peuce*, *Pinus sylvestris*, roots, soil compaction, temperature, axial growth, lateral growth

1. Introduction

It is well known that two of the principal soil physical factors that affect root growth are its mechanical strength and temperature. Soil compaction, which results in mechanical impedance that might restrict root growth, arises from mainly externally applied forces such as trampling by animals or farm and tillage equipment and even a small increase in compaction can result in large decrease in root growth and major changes in root morphology. The type of soil strength characteristics that are favourable to plant growth are closely connected with the nature of the plant (Gonzalez-Ollauri and Mickovski, 2017a) and the temperature at which it grows. Root systems grown in low temperatures are often smaller and less branched which means they exploit a smaller soil volume for plant nutrients and water, and are expected to require a higher uptake rate of nutrients and water per unit length to keep up with the demand.

Despite the wide coverage of the effects of mechanical impedance on root growth and development in the literature (Stokes et al, 2014), almost all studies have concentrated on crops or other fast growing plants. Similarly, only a few investigations have been focused on the influence of temperature on root extension or lateral root proliferation in trees. This study is an attempt to investigate the root development of two *Pinus* species common to the Mediterranean region, grown in different soil consistencies and temperatures and to explore the influence of temperature and soil compaction on the axial and lateral root development. The results of this study might deepen the knowledge on the most important factors influencing root development in the early stages of growth, and will surely add to the number of new tree species investigated. Additionally, the results of this study will enable the foresters and eco-engineers in the Mediterranean region to assess the potential of these pine species for remediation of natural disasters such as forest fires, erosion and landslides.

2. Material and Methods

Ninety 2-year-old Scots pine (*Pinus sylvestris*) and 90 Macedonian pine (*Pinus peuce*) seedlings were planted in containers containing brown humus soil (clayey sand with organic matter of 20% by weight) sieved through 2 mm sieve and with dry weight of 1.9 kg m⁻³. Three containers with 10 seedlings each were packed using 300 J m⁻³ compaction energy per pot (compact soil), another three using 150 J m⁻³ compaction energy per pot (semi-compact soil) and the last three without compaction (loose soil). The plants were grown in three separate glasshouse cubicles with 12 hour daylight growing conditions and at a constant temperature (15°C, 20°C, and 25°C respectively). Containers were arranged so that there were ten seedlings of each species in compact, semi-compact and loose soil at each of the three different temperatures.

The resistance of the soil to static penetration was tested using a pocket penetrometer at four different depths: 2.5 cm, 5 cm, 7.5 cm, and 10 cm. The root system architecture and distribution were recorded before planting and after 3 months growth, together with the maximum axial length of the root system, number of 'major' laterals (defined as lateral roots longer than 20 mm) per seedling, and the root diameter 5 cm below the root apex of

every seedling. Analysis of variance (ANOVA) was then used to calculate the significance of different factors (species, temperature, soil consistence) on the axial root growth of the seedlings, as well as on the increase of the number of major laterals over time.

3. Results and Discussion

Penetrometer readings showed an increase in penetration resistance (soil compaction) with depth ranging from 0.981 kPa for loose soil at 2.5 cm depth, to 25.01 kPa for compact soil at 10 cm depth. The greatest differences in soil density were found in the uppermost layers of the soil where the majority of roots were located.

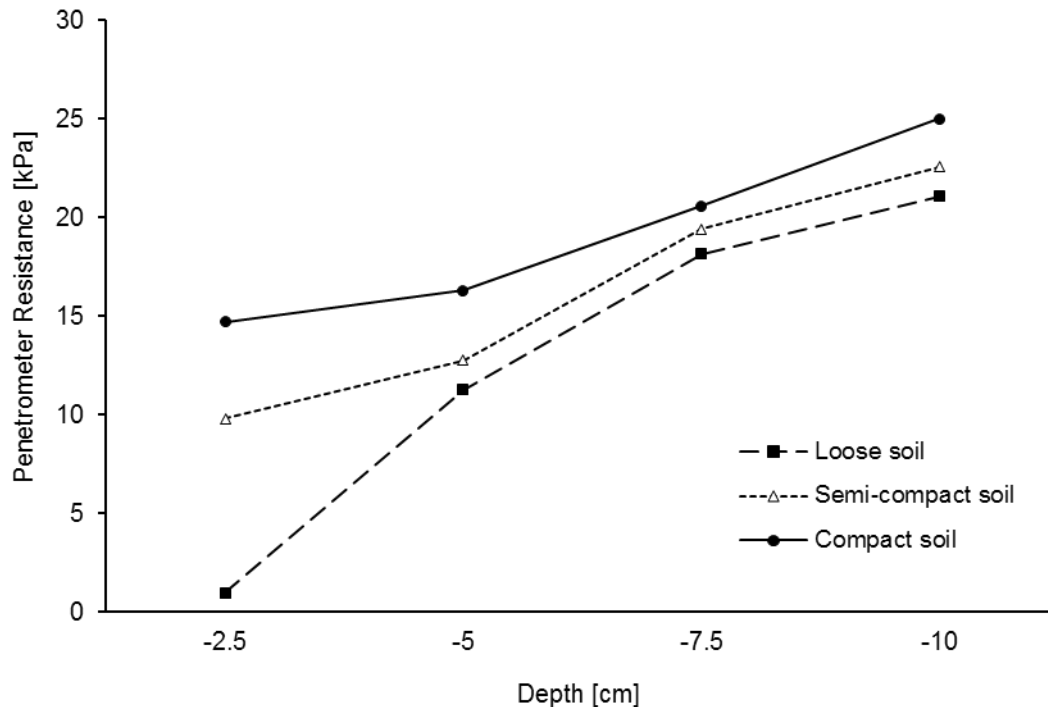


Figure 1. Soil penetration resistance with depth in the three differently compacted soils.

The growth rate for both pine species (Figure 2) was affected by three factors: the species, degree of soil compaction, and temperature.

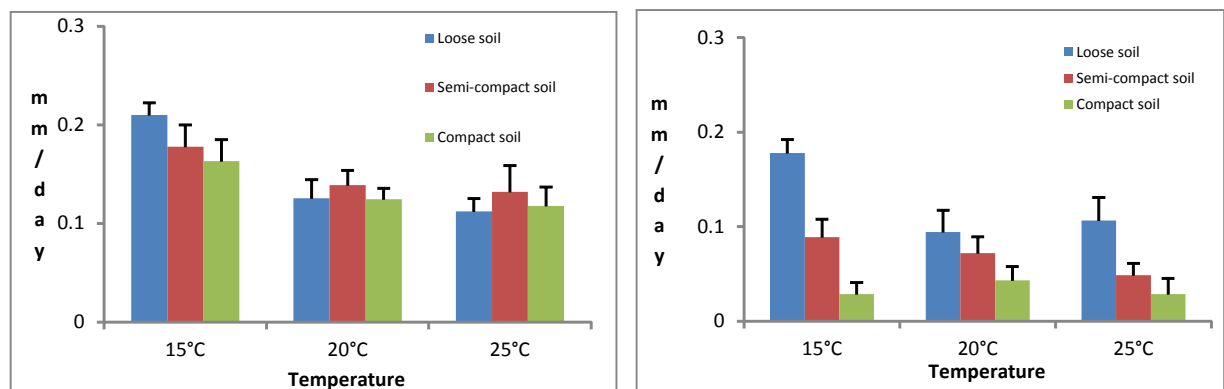


Figure 2. Average axial root growth rate of a) *Pinus sylvestris* and b) *Pinus peuce* seedlings grown at three different temperatures (15°C, 20°C, and 25° C) and in three different soil consistencies (loose, semi-compact, compact). Error bars indicate + SD.

The average rate of axial growth for *P. sylvestris* was higher than the average axial increase slope for *P. peuce*. Loose soil enabled a greater mean increase in axial root length for the seedlings of both species. This was always followed by the increase

of the root length of the seedlings grown in semi-compacted and compacted soil. The seedlings grown at 15°C had greatest mean increase in the axial length of their roots for both species, followed by the ones grown at 20°C and at 25°C which had elongated least of all. The two-way ANOVA also showed that there was no significant interaction ($p>0.05$) between temperature and soil consistency in either species. The average increase in the number of new major laterals for *P. peuce* seedlings was significantly lower than the average increase in the number of major laterals for *P. sylvestris*. The rates of increase of radial root diameter showed a tendency to increase with increase in the soil compactness and temperature

4. Conclusion

This study showed both similarities and differences in the root growth in two *Pinus* species subjected to different soil consistencies and temperatures. The similarities lay in the fact that the rate of axial development of the root systems of both species decreased with an increase in soil compaction (though this was not statistically significant in *P. sylvestris*), even though the levels of compaction were well below the maximum roots are capable of withstanding which is consistent with previous studies (Mickovski and Ennos, 2003). Both species also had the largest increase in axial length of their root systems at 15°C, which might be due to the optimal temperature for root elongation rate. Furthermore, in both species, soil consistency had no significant effect on lateral root proliferation; they overcome even the strongly compacted soil. The differences between the species lay in the extent of lateral root proliferation. While *P. sylvestris* proliferated fewer laterals as the temperature increased, the temperature seemed to be a non-significant factor in the lateral root development of *P. peuce* seedlings.

This study showed that the root elongation rate is negatively correlated with mechanical impedance of the soil since the elongation was lowest in the compacted media and increased as the soil compaction level decreased. The decrease of the elongation rate with the compaction might result from the reduction in the rate of cell elongation and possibly from a decrease in cell production rate. It might also be a result of a smaller difference between the cell pressure and the resistance offered by the soil matrix. Bearing in mind that the roots penetrate soil by an alternating series of radial and axial enlargements, it is clear that they have to overcome soil mechanical resistance in both the axial and radial direction, and/or adapt and change physiologically to the stresses encountered as argued by Mickovski and Ennos (2003). Root growth is thus expected to be very slow during early growth, since the plant will still be suffering from a plant check or time lag in production of adventitious roots.

The variation in elongation rates for various plants reflect the genetic difference among species as well as the effects of other factors such as root system architecture (Tardio et al, 2016). This is important for competition between species and for allowing one genotype to grow better than the other at a specific location. This is also important because both pine species investigated are common to the Mediterranean region (Savill and Mason 2015) where they can be used for prevention and mitigation of natural disasters such as forest fires, erosion and landslides. The results of this study could be applied for other tree species that encounter particularly dense soil conditions in some Mediterranean soils or to allow foresters and landscape managers to select appropriate species for specific climate and soil condition in order to achieve the environmental and engineering effects such as stability, sustainability and resilience (Mickovski and Thomson, 2016; Gonzalez-Ollauri and Mickovski, 2017b).

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